JOURNAL

OF THE

ASIATIC SOCIETY OF BENGAL.

Part II.—PHYSICAL SCIENCE.

No. II.—1876.

VII.—*An Account of Experiments made in* 1875 *and* 1876 *in various parts of India, for the purpose of comparing the observed Temperature of the Dew-point with that computed from the Psychrometer by different Methods of Reduction.*—*By* HENRY F. BLANFORD, *F. G. S., Meteorological Reporter to the Government of India.*

(Received May 29th ;—Read June 7th, 1876.)

The observations of which the results are detailed and discussed in this paper, were made with the special object of ascertaining how far the usual methods of computing the hygrometric state of the atmosphere from observations of the dry and wet bulbs thermometers, under the conditions* now adopted at Indian meteorological observatories, afford trustworthy results; more especially in the extremely dry atmosphere of the interior of India during the hot season. The observations are to a certain extent desultory, having been made during inspection tours in different parts of India, and under various conditions of exposure ; and the results shew some discrepancies, greater than might be expected from more systematic work, and had there been means at hand to introduce such improvements in the manipulation of the hygrometer as experience has suggested. Causes of disturbance, which would produce but little effect in a more humid atmosphere, become influential when the dew point is 40° and

* The thermometers are exposed on a frame with 1 or 2 cross bars (generally protected by wire netting at back and front) under a thatched shed open on all sides to the wind. Where properly constructed the shed is 20 ft. long by 12 ft. wide, but some are smaller than this.

more below the temperature of the air, and observations made at a distance from all the convenient appliances of a physical laboratory, in hot winds and under the intense glare of an Indian sun, are not easily endowed with that precision which is desirable and which is easily to be attained in a well fitted observatory of a high class. I can only say that I have endeavoured to take all such precautions as were practicable and if the range of individual error is on the whole considerable, I believe that the mean result affords a trustworthy criterion of the comparative value of the psychrometric methods; and that, with proper precautions, very trustworthy data of the hygrometric state of the atmosphere may be obtained with the dry and wet bulb thermometers, at all events when the humidity does not fall below 20 per cent. of saturation. Greater degrees of dryness I have as yet had no opportunity of testing; though such are prevalent somewhat later in the season than when my observations were made; especially in Sind and the Punjab, and on the plateau of Central India.

The earlier series of observations were made during an inspection tour in the Madras Presidency, in April 1875. I regret that the original rough record has been mislaid, and I am able to give only the means of each set of readings. In these series (Nos. 1 to 13 of the Tables), the means adopted for the readings of the Regnault's hygrometer include the temperatures at which the dew disappeared from the silver capsule of the instrument, which is not the case with the later series. In striking the adopted mean of each set of readings, the mean temperature at which dew was deposited and that at which it disappeared were taken separately, and the mean of the two results adopted as the dew-point. The difference, however, rarely amounted to a degree, and is very small in comparison with the difference of the temperature and that of the dew-point.

The later series were made during a recent tour in Upper India, in the months of March and April. The air temperatures are generally lower than the Madras series, but the dew-points are proportionally lower. They indicate a very dry atmosphere, although not so low a relative humidity as is shewn later in the season by the registers of many stations in the interior.

The same hygrometer has been used throughout. It is one of Casella's manufacture, and is of the form represented in his illustrated catalogue; it has a single capsule, the air-thermometer being freely exposed; and the evaporation of the ether is accelerated by blowing from the mouth through a piece of elastic tubing about 15 inches in length. Both the thermometers have been verified by myself; at the freezing point by immersion in crushed ice; and through the range of observation, by comparison with a Kew standard (No. 374) which I received in 1868 from Prof. Balfour Stewart.

At the Madras stations (excepting Trichinopoly and Madras), the psychrometric observations were made with the observatory thermometers

(with small pea-bulbs) which Mr. Pogson had verified by comparison with a Kew standard in his possession.

The Upper Indian series (16 to 21) of psychrometric observations were made with a pair of Casella's thermometers of the Kew pattern (with small spherical bulbs) mounted, 6 inches apart, on a portable wooden stand, in such manner that the free access of air is unimpeded in all directions. Both thermometers have been compared in water with my Kew standard and have also been verified at the freezing point. The wet bulb was covered with a single thickness of old thin calico; the water bottle was placed 2 inches to the side of the bulb, with the water level $\frac{1}{4}$ inch below it, and communication was made by a well-washed lamp-wick of some dozen threads of coarse yarn. Care was taken that the bulb was at all times well moistened.

The psychrometer observations at Trichinopoly, Madras, and Calcutta were taken with a sling thermometer, *viz.* that of the hygrometer, in the intervals of the dew-point observations.

In most cases the readings of the instruments were made by two observers, one of whom (myself) read off the Regnault, and the other the psychrometer, on the dew-point signal being given by the first observer. In very dry states of the atmosphere, the mercury of both the dry and wet bulbs is in a state of constant oscillation, through a range of a degree or more; moreover, unless the silver capsule is very highly burnished and free from microscopic scratches, there is considerable difficulty in seizing the exact temperature at which dew appears, since the quantity deposited is very small and but slightly dulls the surface even at 3 or 4° below the dew-point. The surface of the capsule having been polished with plate-powder, was not in the best condition, and it is likely that some of the discrepancies to be noticed in the tables may have been in some measure due to this; but I do not think that the error thus arising could exceed a few tenths of a degree, as great watchfulness was exerted, and any observation that appeared doubtful at the time was rejected. I shall in the sequel suggest some precautions and improvements which may be useful to future observers.

In the following Tables, the dew-point determined directly by the hygrometer is compared with that computed from simultaneous observations of the psychrometer by each of the three methods in common use. The first is August's formula as corrected by Regnault and adapted to English standards. It is given at page 47 of Guyot's Hygrometric Tables, for wet-bulb temperatures above the freezing point as follows:

$$x = f - \frac{0{\cdot}480 \times \frac{5}{9}(t-t')}{610 - \frac{5}{9}(t'-32)}h = f - \frac{0{\cdot}480\,(t-t')}{1130-t'}h$$

wherein x is the tension of saturated vapour at the temperature of the dew-

point, f the same at the temperature t' of the wet bulb, t the air temperature and h the barometer reading.

The development of this formula may be found in Regnault's original paper, published in the *Comptes rendus* for April 1845, or in the translation given in the 3rd Volume of Taylor's Scientific Memoirs. Also in the article 'Hygrometry' in Watts's Chemical dictionary. It is based on the assumption that the film of air around the wet bulb is saturated with vapour, and that the heat lost by this film of air, in falling to the temperature of the wet bulb, is exactly equal to the latent heat absorbed by the water which passes into vapour in the act of bringing it to saturation.

The second is Apjohn's well-known formula, given in almost all English manuals of physics and meteorology, as follows, for temperatures of t' above the freezing point:

$$x = f - \frac{t-t'}{88} \cdot \frac{h}{30}$$

The development of this formula was given by Dr. Apjohn in the Transactions of the Royal Irish Academy, November 1834, and is reproduced in Professor Everett's translation of Deschanel's Natural Philosophy. It proceeds on precisely the same assumption as the previous formula, but assumes a mean constant instead of a variable value for the latent heat of vapour, by which the formula is somewhat simplified; the difference of the results afforded by Apjohn's and August's formula depends, however, mainly on the different values assumed for the constant coefficients common to the two formulæ.

In applying these formulæ, I have taken the vapour-tensions from a table lately computed for the mean latitude of 22°, from that given by the Rev. Robert Dixon for the latitude of Dublin.

Glaisher's factors, with which the third values of the dew-point are obtained, are those published in 1856. Their use is of course open to the objection that they take no account of variations of barometric pressure. As a rule they seem to give a result too low with a high relative humidity and too high with low humidities.

TABLE I. A.—*Abstract of observations made in* 1875, *chiefly in the Madras Presidency.*

Place.	Date.	Hour.	Series.	Regnault's Hygrometer.			Mason's Hygrometer.				Red Bar.	Computed D. P.			Remarks.
				No. of obs.	Air.	D. P.	No. of obs.	Dry.	Wet	Diff.		Aug.	Apj.	Glaish.	
		h. m.													
Secunderabad. In thermometer shed of observatory.	April 6th, 1875.	12 40 to 12 50	1	6	92·3	47·6	2	92·4	67·9	24·5	28·07	50·1	53·7	53·0	Air in thermometer shed almost motionless. Anemometer on rock, 4 miles per hour. Wind N by E. to ENE. Cloud 5.
		13 5	2	1	93·5	52·5	1	93·4	70·1	23·3		55·8	58·4	55·9	
		13 8 to 13 10	3	6	94·5	50·5	4	94·8	70·6	24·2		55·4	58·5	56·1	
		13 25 to 13 31	4	12	92·8	50·9	3	92·7	69·6	23·1		54·8	57·9	55 5	
Bellary. In thermometer shed of observatory.	April 9th.	9 24 to 9 29	5	7	94·9	54·2	4	94·0	69·7	24·3	28·40	53·8	57·0	55·1	Wind blowing gently through thermometer shed. SE to SW. Anemometer on building 10 miles per hour. Light cirri.
		9 26	6	2	95·1	58·1?	1	94·7	68·9	25·8		51·1	54.8	53·4	
		9 30 to 9 35	7	8	95·4	51·7	4	94·7	68·4	26 3		49·7	53.6	52·6	
		9 50 to 10 0	8	9	96·1	47·8	4	95·8	66·6	29·2		43·2	48.4	49·4	

TABLE I. A.—*Continued.*

PLACE.	Date.	Hour.	Series.	REGNAULT'S HYGROMETER.			MASON'S HYGROMETER.				Red Bar.	COMPUTED D. P.			REMARKS.
				No. of obs.	Air.	D. P.	No. of obs.	Dry.	Wet	Diff.		Aug.	Apj.	Glaish.	
		h. m.													
Coimbatoor. In thermometer shed of observatory.	April 16th.	15 33 to 15 54	9	8	96·7	48·6	5	96·8	68·9	27·9	28·39	49·1	53·2	52·4	Anemometer, on shed, 5 miles an hour. Breeze occasionally felt in shed. Wind E. Fanning wet bulb produced no reduction.
		15 50	10	1	96·1	46·5	1	96.4	68·5	27·9		48·4	52·6	52·0	
		16 35 to 16 50	11	10	95·7	52·8	5	95·3	69·9	25·4		53·1	56·6	54·7	
Trichinopoly. In verandah on 1st floor.	April 21st	17 25 to 17 45	12	6	89·6	71·0	3	89.6	77·2	12·4	29·35	71·7	72·7	69·4	Wet B. temperature taken with D. P. thermometer of Regnault with wet muslin on bulb used as *thermomètre fronde*.
Madras. In verandah of upper storey.	April 25th.	11 40 to 12 3	13	5	97·2	61·1	3	97·0	74·1	22·9	29·72	60·8	63·4	60·6	As the previous series.
Calcutta. In ground-floor room, windows open 2 sides.	June 18th.	11 15 to 11 22	14	9	84·8	77·8	2	84·2	79·4	4·8	29·60	77·4	77·7	76·2	As the previous series.
Calcutta, as above.	June 19th.	9 30 to 9 45	15	12	83·8	77·5	2	83·8	79·7	4·1	29·55	78·0	78·3	77·0	As the previous series.

TABLE I. B.—*Observations made in* 1876 *in Upper India.*

Place.	Date.	Hour.	Ser.	Regnault's Hygrometer.				Mason's Hygrometer.					Red Bar.	Computed D. P.			Remarks.
				Obs. Air.	Obs. D.P.	Mean Air.	Mean D. P.	Obs. Dry.	Obs. Wet	Mean Dry.	Mean Wet.	Diff.		Aug.	Apj.	Glaish.	
Allahabad in West verandah of Mr. Elliott's house.	March 16th, 1876.	7 h.	16	77·2	47	77·2	47	77·4	61·2	77·4	61·2	16·2	29·54	47·2	50	49·9	Very open, no chiks: fresh breeze from West.
		15 h.	17	87·1	46			87·1	65·5								
				87·2	46·5			87·3	65·2								
				87·1	45·3	87·1	45·7	87·3	65	87·3	65·2	22·1	29·45	47·5	51·1	51·1	Wind perceptible in verandah; from W.
				87·1	45			87·3	65								
				87·3	45·5			87·3	65·5								
Agra in West verandah of the dâk bungalow.	March 18th.	Noon.	18	85·2	38·4			85·6	60·4								
				85·2	40			85·6	60·6								
				85·4	40·1			85·7	60·5								
				85·4	42	85·8	40·7	85·8	60·6	86·1	60·8	25·3	29·35	34·6	40·5	44·4	Light wind from West; chiks up. Cloud cirro-stratus 5.
				85·9	42·5			86·2	61·1								
				86·6	41·7			86·9	61·6								
				86·7	40			87	60·6								
Lahore in West verandah of Dr. Neil's house.	March 26th.	14 h.	19	81·9	40			82	61·8								
				82·8	41·1			82·7	62·7								
				82·8	39·9			82·9	62·4								
				82·7	39·4	82·7	39·8	82·9	62	82·9	62·3	20·6	29·08	44·4	48·0	48·5	Chiks down; wind from W. scarcely felt in verandah. Cloud cirro-stratus 8.
				82·7	39·4			82·9	62·1								
				82·9	40·4			83·4	62·6								
				83·1	39·2			83·4	62·6								
				82·8	39·4			83·1	62								

TABLE I. B.—*Continued.*

Place.	Date.	Hour.	Ser.	Regnault's Hygrometer.				Mason's Hygrometer.					Red Bar.	Computed D. P			Remarks.
				Obs. Air.	Obs. D.P.	Mean Air.	Mean D. P.	Obs. Dry.	Obs. Wet	Mean Dry.	Mean Wet.	Diff.		Aug.	Apj.	Glaish.	
		h. m.															
Lahore in thermometer-shed. Mayo College.	April 4th, 1876.	9 15	20	72·9	37·5	73·2	37·8	72·8	55·3	73	55·6	18·4	29·18	34·9	39·2	41	A light breeze from the West blowing through the shed.
				73	37·5			72·8	55·8								
				73	38·3			72·9	55·3								
				73·3	37·7			72·8	55·8								
				73·3	37·4			72·9	55·8								
				73·5	37·6			73·3	55·8								
				73·3	37·8			73·3	55·3								
				73·2	37·3			73	55·6								
		9 35	21	74·6	36·6	74·8	37·2	74·9	56·8	74·9	56·9	18·0	29·18	38	41·8	43·9	Ditto.
				74·8	36·5			74·9	56·8								
				74·8	38			74·9	56·9								
				74·8	37·5			75	57								
				74·8	37·6			74·9	57								
				74·8	37·3			74·9	56·8								
				74·8	37·1			74·9	56·8								

Assuming the direct dew-point determinations to be correct, the following are the errors shewn by the several computations.

TABLE II.—*Errors of Dew-points computed from Psychrometer by different methods.*

PLACE.	Series.	D. P. below air.	ERRORS.			CONDITIONS.
			Aug.	Apj.	Glaish.	
Secunderabad, ..	1	44·7	+ 2·5	+ 6·1	+ 5·4	In thermometer-shed.
Do. ..	2	41·0	+ 3·3	+ 5·9	+ 3·4	
Do. ..	3	44·0	+ 4·9	+ 8·0	+ 5·6	
Do. ..	4	41·9	+ 3·9	+ 7·0	+ 4·6	
Bellary, ..	5	40·7	— 0·4	+ 2·8	+ 0·9	Do.
Do. ..	6	? 37·0	? — 7·0	? — 3·3	? — 4·7	
Do. ..	7	43·7	— 2·0	+ 1·9	+ 0·9	
Do. ..	8	48·3	— 4·6	+ 0·6	+ 1·6	
Combatoor, ..	9	48·1	+ 0·5	+ 4·6	+ 3·8	Do.
Do. ..	10	49·6	+ 1·9	+ 6·1	+ 5·5	
Do. ..	11	42·9	+ 0·3	+ 3·8	+ 1·9	
Trichinopoly, ..	12	18·5	+ 0·7	+ 1·7	— 1·6	In verandah. Sling-thermometers.
Madras, ..	13	31·1	— 0·3	+ 2·3	— 0·5	Do. Do.
Calcutta, ..	14	13·0	— 0·4	— 0·1	— 1·6	In sitting room. Do.
Do. ..	15	6·3	+ 0·5	+ 0·8	— 0·5	
Allahabad, ..	16	29·3	+ 0·2	+ 3·0	+ 2·9	In verandah.
Do. ..	17	41·4	+ 1·8	+ 5·4	+ 5·4	
Agra, ..	18	45·1	— 6·1	— 0·2	+ 3·7	Do.
Lahore, ..	19	42·9	+ 4·6	+ 8·2	+ 8·7	Do.
Do. ..	20	35·4	— 2·9	+ 1·4	+ 3·2	In thermometer-shed.
Do. ..	21	37·6	+ 0·8	+ 4·6	+ 6·7	
Mean,* ..	..	..	+ 0·46	+ 3·70	+ 3·00	

In most of the above series the computed is higher than the observed dew-point, especially when the computation is made by Apjohn's formula. The exceptions are series 6 at Bellary (in which, however, I think the dew-point observation is open to considerable doubt†) and series 14 at Calcutta and 18 at Agra, in which the computed values are too low.

The following table exhibits the mean results of the table of errors, *viz.*, the numbers of sets of observations which give excessive or deficient dew-point temperatures, the mean error, the extreme errors and the sums of the squares of the errors, positive and negative, by each method of reduction.

* Omitting series 6.

† It is not unlikely that there has been some error in the determination of the dew-point by the direct method, which, it may be observed, is derived from 2 observations only (one of deposition and one of disappearance). These observations were taken in among the 7 of the preceding series, and I have separated them on account of their discrepancy. I have not, however, felt justified in rejecting them, since I have no knowledge of any cause of error affecting them which might not have affected others.

Table III.

Method.	Sets obs.		Mean	Highest.	Lowest.	Sums of squares of errors.	
	in excess.	in defect.	Error.	+	—	+	—
By August's form.,	13	7	+ 0·46	4·9	6·1	86·13	71·19
„ Apjohn's „	18	2	+ 3·70	8·0	0·2	406·98	0·05
„ Glaisher's facs.	16	4	+ 3·00	8·7	1·6	327·80	5·62

If we take those series only that were made in the thermometer-sheds, with a mean difference of 42·7° (extremes 35·4 and 49·6) between the air-temperature and the dew-point, the errors of the several methods are as follow:

Table IV.

Method.	Series.		Mean	Highest.	Lowest.	Sums of squares of errors.	
	in excess.	in def.	Error.	+	—	+	—
By August's form.,	8	4	+ 0·68	4·9	4·6	60·95	33·73
„ Apjohn's „	12	0	+ 4·40	8·0	—	292·76	—
„ Glaisher's facs.,	12	0	+ 3·62	6·7	—	200·85	—

The first general conclusion to be drawn from this discussion is that while the results shew a considerable range of error (which may be in part due to a faulty use of the Regnault), on the mean of all the observations, the dew-point computed by August's formula from observations of the psychrometer made under an open shed, comes very near to that observed with Regnault's hygrometer, even when the dew-point is more than 40° below the temperature of the air. Both Apjohn's formula and Glaisher's factors appear to give too high a result.

With regard to the less complete exposure afforded by a verandah, or any place through which the air is not moving freely, the two Allahabad series (16 and 17) and the first Lahore series (19) shew that the psychrometer, in such a situation, gives too high a humidity by all the methods of reduction; and the Secunderabad series (1 to 4) though made under a shed, tend to support the conclusion that a still atmosphere is prejudicial to all the psychrometric method. These observations were taken on the day of

the solar eclipse; the sky was cloudy; and in the shed, the air was appreciably motionless. The shed was screened from such little wind as stirred the anemometer, partly by a neighbouring building, and partly by rising ground. Even on the top of a neighbouring rock, on which the anemometer was fixed on a post, there was sufficient air only to stir the vanes at intervals, and in the shed the atmosphere was still and oppressive. Hence it would appear that under all conditions a still atmosphere is unfavourable to the accuracy of the psychrometric method. This conclusion has already been drawn by previous observers.

These conclusions must nevertheless be regarded as provisional only, until similar experiments shall have been made with more consistent results.

I have said that the experience now gained has shewn the necessity for some additional precautions and improvements in the use of the Regnault's hygrometer in a very dry atmosphere; and I will mention these, in the hope that other observers may be induced to pursue the investigation. These are—

1*st.*—The silver capsule must be highly burnished and free from microscopic scratches, which so reflect the light as to make it very difficult to seize the moment of dew-deposition. This surface can be given only by hand-polishing with the softest part of the skin (care being taken that the skin is free from grit) and with the application of a little carefully kept jeweller's rouge. Plate powder, wash leather, and soft rag are equally to be avoided; and when once polished, great care must be taken to preserve the instrument from grit and dust. The Indian rubber tube which communicates with the air pipe, must be kept apart from the instrument when not in use, or the sulphur evaporating from it will quickly blacken the surface.

2*nd.*—The mouth tube of Casella's instruments should be replaced by a finger bellows or some other portable form of blower which can be worked rapidly but is under complete control; or else the instrument should be adapted for the use of an aspirator.

3*rd.*—A black screen should be so placed at the side of the instrument that its reflection may be thrown from one side of the silver capsule to the eye.

4*th.*—In experimenting in the open air, great care must be taken not to sit to windward of the hygrometer and not to approach it nearer than is absolutely necessary to take the reading. The mouth and nose should be covered with a handkerchief during the experiment to prevent any breath reaching the instrument.

5*th.*—In very dry states of the atmosphere it is best to take a preliminary observation in which the blowing is continued until a decided and comparatively copious deposit is formed, noting as nearly as possible the temperature at which it first appears. This observation is made for guid-

ance only. In the subsequent observations, by regulating the flow of air, the temperature is to be lowered very gradually as it approaches the point noted; and on the first appearance of dullness, the blast is arrested, but the reading of the thermometer is not to be taken till it reaches its lowest point.

There are other points to be attended to, which unpractised observers frequently neglect. One is to keep the eye on the same level as the top of the mercurial column of the thermometer (whether that of the hygrometer or psychrometer) when taking the reading, in order to avoid the errors of parallax. This is a point which it is most difficult to enforce on those who are not thoroughly trained observers, and such persons are few in India.

The capsule must not be more than three parts filled with ether, and at first a very gentle blast must be applied or the ether will spill over the surface of the capsule; and if not perfectly pure, will impair its polish. The ether must be free from water.

VIII.—*List of the Birds collected on the Expedition into the Dafla Hills, Assam, together with those obtained in the adjacent Darrang Terai.—By Major* H. H. Godwin-Austen, *F. R. G. S., F. Z. S., &c., Deputy Supt. Topographical Survey of India.*

(Received May 26th;—Read June 7th 1876).

(With Plates III & IV.)

Having been placed in charge of the survey-party attached to the force which, under the command of Brigadier-General W. J. F. Stafford, C. B., penetrated into the Dafla Hills during the winter of 1874—75, an opportunity was presented of forming collections in a portion of the N. E. Frontier which had never before been visited. It was an opportunity not to be lost, as it would extend considerably the undoubted range of many interesting or little-known Himalayan forms towards the east into the Indo-Burman and West China faunas; while there was also the great probability of discovering new forms, not only among the birds, but in other branches of zoology. On arriving in Calcutta in October 1874, I received much assistance and advice from Messrs. Wood-Mason and G. Nevill, of the Indian Museum, and at the recommendation of the former was permitted to entertain and take with me a native taxidermist, with extra coolies for the carriage of specimens, store-boxes, &c.; my cordial thanks are due for this aid and for the interest shewn by the above-named gentlemen. The list shews that I was tolerably successful, notwithstanding that the force did not penetrate beyond the first large valley at the back of the outer range,